Experimental investigation of partial demodulation of 85.3 Gb/s DQPSK signals

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Abstract

We experimentally assessed the performance of partial DQPSK at 85.3 Gb/s, and demonstrated improved tolerance to ASE noise, chromatic dispersion and fibre nonlinearity in comparison to conventional DQPSK.

Introduction

The recent drive towards a 100G Ethernet standard and increase in traffic demand will require the next-generation fibre-optic systems to carry WDM channels with bit rates >100 Gb/s on a single wavelength [1,2]. Differential quadrature phase shift keying (DQPSK) is recognised as a promising format for >100 Gb/s transmission systems since it operates at a half the baud rate for the same total bit rate compared to binary systems and, hence, requires lower bandwidth and has higher tolerance to chromatic dispersion (CD) and PMD [3]. Typically direct-detection DQPSK receiver consists of two parallel Mach-Zehnder interferometers (MZI) with one-symbol period delay between the two arms and ±π/4 phase differences to obtain in-phase (I) and quadrature (Q) tributaries [1,4] followed by balanced detectors. This demodulation scheme is sub-optimal and results in an OSNR/bit penalty (~1.4 dB for 10^{-3} bit-error-rate (BER)) compared to the differential binary phase shift keying (DBPSK) with the same baud rate [5]. It has been shown that partial demodulation, where the delay between arms of MZI is reduced to less than one bit period and a single bit partially interferes with its neighbour and partially with itself, increases the CD and narrow optical filtering tolerance for 43 Gb/s DBPSK signals [6]. In this paper we demonstrate, for the first time, the use of partial demodulation for 85.3 Gb/s DQPSK signals and compared it performance with conventional DQPSK. We show that PDQPSK improves receiver sensitivity and significantly increases the tolerance to CD and nonlinear distortion.

Transmitter and receiver design

To generate the 85.3 Gb/s DQPSK signal, the output of the DFB laser, operating at a wavelength 1554.94 nm, was launched into a GaAs triple Mach-Zehnder modulator with 3 and 6 dB electrical bandwidths of 26 and 31 GHz respectively [7]. The modulator was driven by 48 bits decorrelated non-inverted and inverted 42.65 Gb/s 2^{21} de Bruijn sequences. The signal was noise loaded and filtered with 100-GHz channel spaced demultiplexer (flat-top optical transfer function with 3 dB bandwidth of 0.65 nm). At the receiver the two outputs of the MZI demodulator were received by a pair of balanced detectors. The aim of this work was to compare the performance of a conventional DQPSK (CDQPSK) demodulator with 1-symbol period delay (42.65 GHz free spectral range (FSR)) to that of a partial DQPSK (PDQPSK) demodulator with 85% of a symbol period delay (50 GHz FSR)). The amplitude imbalance and delay between the two demodulator outputs were optimised in both cases. The electrical output of the differential receiver was connected, via the clock and data recovery, to a bit-error-rate test set. The parameter for comparison was the OSNR (0.1 nm resolution bandwidth (RBW)) required to achieve 1×10^{-3} BER.

Results and discussion

First, the back-to-back (BTB) performance of CDQPSK and PDQPSK was evaluated. The results were also compared to (C/P)DBSK and on/off keyed (OOK) 42.65 Gb/s signals, generated by the same modulator by analysing the measured BER vs OSNR/ bit (Fig. 1). For CDBPSK the required OSNR to achieve 10^{-3} BER was 15 dB which, as expected,

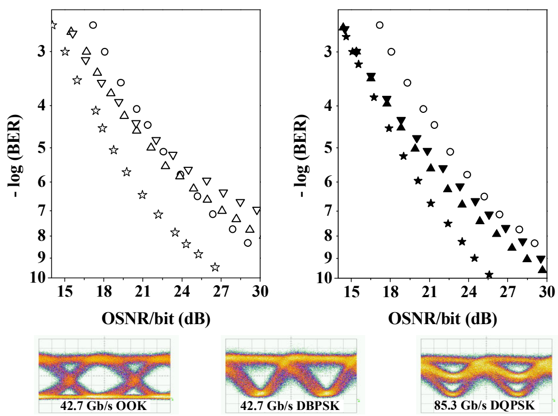

Fig. 1. Top: BER vs OSNR/bit for conventional (left) and partial (right) demodulation. Open symbols: circles – OOK; stars – CDBPSK; triangles CDQPSK. Solid symbols: stars – PDBPSK; triangles – PDQPSK. Up/down triangles represents Q and I DQPSK tributaries. Bottom: optical eye diagrams for OOK, DPSK and DQPSK signals.

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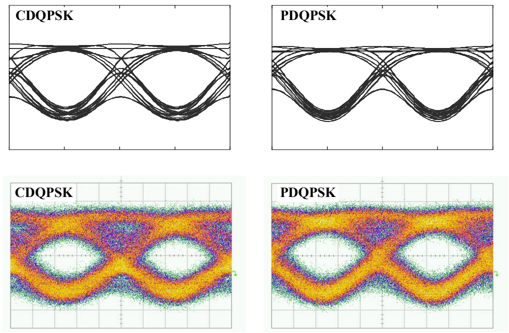

Fig. 2: Simulated (top) and experimental (bottom) demodulated eye diagrams for CDQPSK and PDQPSK signals.

is 3 dB lower than for OOK [8]. Note, that the approx. 2 dB higher required OSNR than reported in [6] for CDPSK and the slope change of BER line are the result of the limited modulator bandwidth. The use of PDBPSK improves the error floor at 10^{-9} BER level and has a negligible (< 0.1 dB) sensitivity penalty compared to CDBPSK, similar to the results reported in [6]. The OSNR/bit penalty for CDQPSK is 1.6 dB, compared to the CDBPSK, close to the 1.4 dB theoretical value, obtained in [5]. This penalty was reduced to 0.4 dB by using partial demodulation and the error floor at 10^{-8} BER level was eliminated. C and P DQPSK experimental (35 dB OSNR) and simulated (using 2^9 de Bruijn sequences) demodulated eye diagrams (Fig 2) show wider eye opening and lower jitter for partial demodulation.

Next the dispersion tolerance of CDQPSK and PDQPSK was investigated using spans of fibre with dispersion over the range ± 80 ps/nm (Fig. 3). The slightly higher penalty for the positive dispersion compared to the negative can be explained by the GaAs modulator chirp. It can be seen that the sensitivity improvement can be maintained when the signal is distorted by CD. The dispersion range for 2 dB 10^{-3} BER required OSNR penalty with respect to the BTB PDQPSK performance was +16/-24 ps/nm and +32/-41 ps/nm, for CDQPSK and PDQPSK respectively.

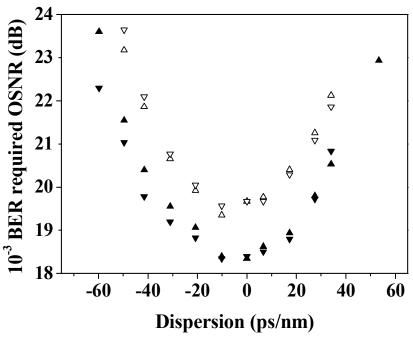

Fig. 3: OSNR required to reach 10^{-3} BER vs chromatic dispersion. CDQPSK – open triangles; PDQPSK – solid triangles. Up and down triangles represents Q and I tributaries.

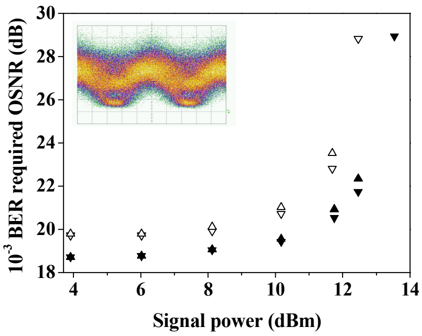

Fig. 4: OSNR required to reach 10^{-3} BER vs signal power. CDQPSK – open triangles; PDQPSK – solid triangles. Up and down triangles represents Q and I tributaries. Inset: DQPSK optical eye diagram at 11.6 dBm signal power and 35 dB OSNR.

Finally we investigated the tolerance of CDQPSK and PDQPSK to fibre nonlinearities. In this case the signal after the transmitter was pre-compensated using +137 ps/nm dispersion (a value selected to increase the nonlinear distortion), amplified and launched into 80 km span of G.652 fibre, with a total dispersion almost exactly compensated at the signal wavelength (1.2 ps/nm). The signal power was varied over the range 3 to 14 dBm and the OSNR required to reach 10^{-3} BER was analysed for CDQPSK and PDQPSK. As shown in Fig. 4 the PDQPSK sensitivity improvement is maintained over the entire input power range. PDQPSK allows a 2.2 dB increase in signal power before the required OSNR penalty reaches 2 dB.

Summary

We have experimentally demonstrated that PDQPSK can improve the BTB sensitivity by 1.3 dB at a bit-rate of 85.3 Gb/s, giving 10^{-3} BER required OSNR/bit only 0.4 dB higher than for 42.65 Gb/s DBPSK signal. We also showed that PDQPSK has 1.8 times higher dispersion tolerance and allowed 2.2 dB signal launch power increase before nonlinear penalty exceeds 2 dB at 10^{-3} BER. This experimental study has demonstrated the suitability of partial DQPSK for 100GbE systems. The authors would like to thank Bookham for the loan of the QPSK modulator, C.R. Doerr from Bell Laboratories, Alcatel-Lucent for the design and fabrication of the PDQPSK demodulator and EU IP Nobel, EPSRC, The Royal Society and RCUK for financial support.

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